Jim Owen

TECHNICAL NOTE

LOCKHEED
Huntsville Research & Engineering Center

Contract NAS8-~~32213~~ 32982 **Date** December 1979 **Doc.** LMSC-HREC TN D697765

Title PRELIMINARY STUDY OF THE DIFFUSER DESIGN REQUIREMENTS FOR SEA LEVEL TESTING OF THE ASE 200:1 AND 175:1 ENGINES

FOREWORD

This report documents the results of a preliminary study to determine diffuser requirements for sea level testing of the ASE engine. The study was performed under Contract NAS8-32982, "Thermal Protection System for Solid Rocket Booster (SRB)." The MSFC Contracting Officer's Representative for this contract is Mr. W. P. Baker.

TECHNICAL DISCUSSION

Design Requirements

1. The diffuser must allow the nozzle to flow full at the 100% P_c and 10% P_c start and run conditions for either nozzle.
2. For the 100% P_c operation it is desirable to not use an auxiliary ejector.
3. The engine operating parameters are presented in Table 1.

Diffuser Design Philosophy

1. Diffuser design based on a 38% starting margin for $P_c = 1500$ psia.
2. Diffuser cooling water requirements based upon operation at $P_c = 2000$ psia without auxiliary ejector.
3. Auxiliary ejector cooling water requirements based on gas turbine gases with total temperature of 2000 R and total pressure of 25 psia.
4. Auxiliary ejector flow requirements based on diffuser operation at $P_c = 200$ psia and 175:1 area ratio nozzle.

Diffuser Design Summary

The final preliminary diffuser design characteristics are presented in Table 2. The diffuser configuration for 100% P_c operation is shown in Fig. 1. The 175:1 engine will require a special 8 deg conical inlet adapter. The diffuser configuration for 10% P_c operation is shown in Fig. 2. In this configuration the 10 degree exit cone frustum is removed and the auxiliary ejector system is installed. The final preliminary design calculations are presented next for the various diffuser segments.

Diffuser Final Calculations

$D_D = 36.00$ in.

$D_{ST} = 26.75$ in.

$A_D/A^* = \left(\frac{36.00}{2.508}\right)^2 = 206.04$

$M_D = 5.64$

$A_{ST}/AD = (26.75/36.00)^2 = .55213$

$A_{ST}/A^* = 206.04 \times .55213 = 113.76$

$M_{ST} = 5.16 \quad P_{T2}/P_{T1}/NS = .0159$

$P_{START} = 14.7/.0159 = 924.53$ psia (Minimum Start Pressure)

Starting Margin for $P_c = 1500$ psia

$$\text{Margin} = \frac{1500 - 925}{1500} = .383 = 38\%$$

Margin for P_c = 2000 psia = .538 = 54%

Diffuser Exit Pressures from Second Throat

For	$P_c = 1500$,	$P_{ex\ ST} = P_c \times P_{T2}/P_{T1}$	= 23.85 psia
"	$P_c = 150$,	" = "	2.39 psia
"	$P_c = 2000$,	" = "	31.80 psia
"	$P_c = 200$,	" = "	3.20 psia

Cooling Water Requirements

Diffuser Tube, 18,800 gpm

Auxiliary Ejector Tube: 3,000 gpm

Note: Potential problem area: Downstream half of straight section of diffuser tube where the heating rate is 500 + Btu/ft^2-sec is going to be too hot to cool below steel allowable temperature, so will require special design. Suggested solution: "Rockhide" coating over steel. (Presently calculated minimum temperature on gas side of steel is 800$^+$ F).

Ejector Design Calculations

Based on 2000 R ejector flow total temperature, an ejector flow rate 10 times the diffuser flow rate should be sufficient based on available data. This flow rate should be verified for final design.

Design ejector for a balanced jet at exit Mach number of 2.0 and $\gamma = 1.3$. Therefore:

For $M_{ej} = 2.0$

$P/P_T = .1305, \quad P_T = 3.20/.1305 \simeq 25$ psia

Throat Density, $\rho^* = \dfrac{25 \times .5457 \times 144}{53.3 \times 1739} = .02119$ lbm/ft^3

$$V^* = 1970 \text{ ft/sec}$$

Throat Area $= A^* = 42/(.02119 \times 1970) = 1.006$ ft^2

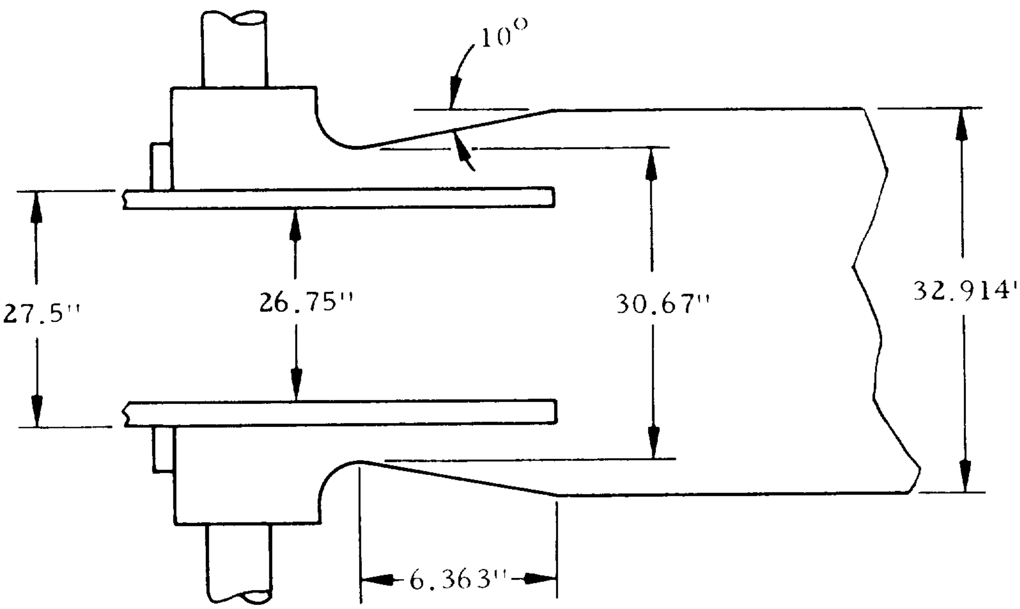
Ejector Exit Area

$A_{ej} = 1.773(1.006) = 1.784$ ft^2

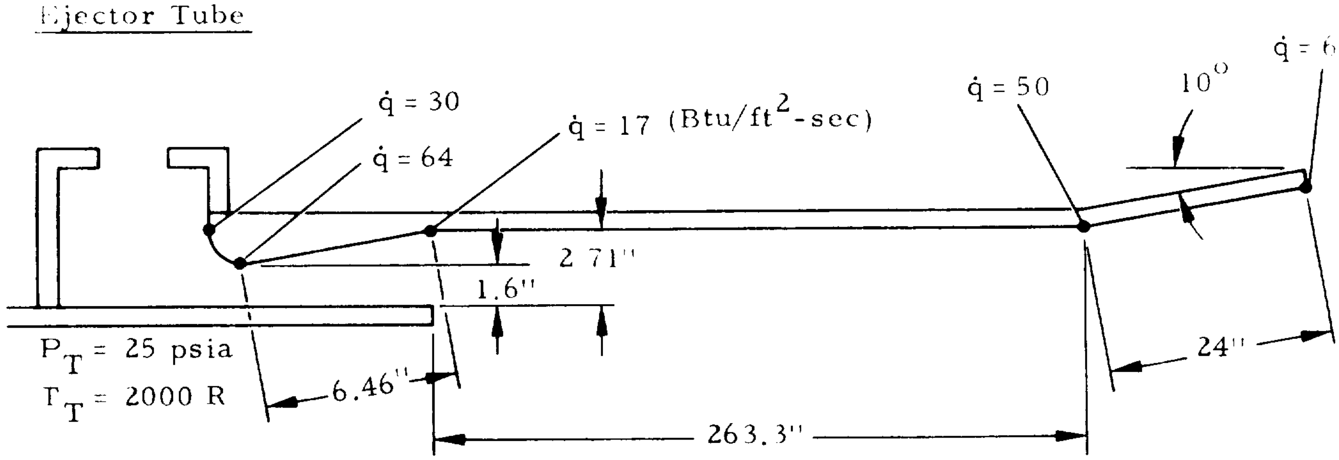
Ejector Normal Shock Pressure at Mach No. 2.

$P_{T_{2\,N/S}} = 25 \times .7006 = 17.52$ psia

This pressure is greater than ambient pressure, therefore, ejector total pressure of 25 psia is sufficient.



Ejector Tube



$H_o = (.3)(2000) = 600$ Btu/lbm

$M_{wt} = 28.5 \quad C_p = .3$ 200% Theoretical Air

$\dot{q} = 3.8\,(P/.85)^{.8} \times (40/X_T)^{.2} = 63.5$ Btu/ft^2-sec (at Throat)

S	P	$\dot{q}$
1.0	25	30.0
2.0	13.6	63.5
8.46	3.7	16.8
271.8	14.7	25.3 x 2 = 50
Exit	14.7	60

Throat Heating Rate Check:

$\dot{q}_{T_{\text{Throat Max}}} = 228 \times (1.0/1.6)^{.2} \times (25/100)^{.8} \times 600/650 = 63.2$ Btu/ft^2-sec (Ratioed from HGF Value)

C. J. Wojciechowski
Heat Protection Systems Group

Approved:

W. G. Dean, Lead Engineer
Heat Protection Systems Group

C. D. Andrews, Supervisor
Flight Technologies Section

Attach: (1) Tables 1 and 2
(2) Figs. 1 and 2

Table 1

ENGINE PARAMETERS FOR DIFFUSER DESIGN

Parameter	Area Ratio	
	175:1	200:1
Chamber Pressure 100% P_c (psia)	2000	1500
Chamber Pressure 10% P_c (psia)	200	150
Propellant Flow Rates 100% P_c (lbm/sec)	42	31.5
Propellant Flow Rates 10% P_c (lbm/sec)	4.2	3.15
Throat Diameter (in.)	2.508	2.508
Exit Diameter (in.)	33.18	35.47
Design Run Time (sec)	2000	2000
Nozzle Exit Angle (deg)	7.0	~ 7.0
γ (effective)	1.22	1.22
Nozzle Exit Pressure 100% P_c (psia)	.59	.38
Nozzle Exit Pressure 10% P_c (psia)	.059	.038
Nozzle Exit Mach No.	5.504	5.61

Table 2

DIFFUSER OPERATING PARAMETERS

Diffuser	
Starting Pressure Operating w/o Ejector (psia)	925
Inlet Duct Diameter (in.)	36
Inlet Duct Length (in.)	18
Second Throat Diameter (in.)	26.75
Length of Second Throat (L/D = 8.0)	214.
Second Throat Inlet Ramp Angle (deg)	12.
Second Throat Inlet Length (in.)	21.8
Adaptor Required for 175:1 Nozzle (deg)	8
Cooling Water Required (gpm)	18,800
Auxiliary Equipment	
2 Stage Cell Ejector (Air or Steam)	
Capable of Pumping Cell Pressure Down to .04 psia (2 mm)	
Exit Plane Ejector Required for Operation at 10% P_c, Ejector Conditions, P_T = 25-30 psia	
Mass Flow Rate = 32-45 lbm/sec.	
Cooling Water Required (gpm) = 3,000	
Diffuser Overall Length	
Without Ejector = 278 in. = 23.2 ft	
With Ejector = 541 in. = 45.1 ft.	

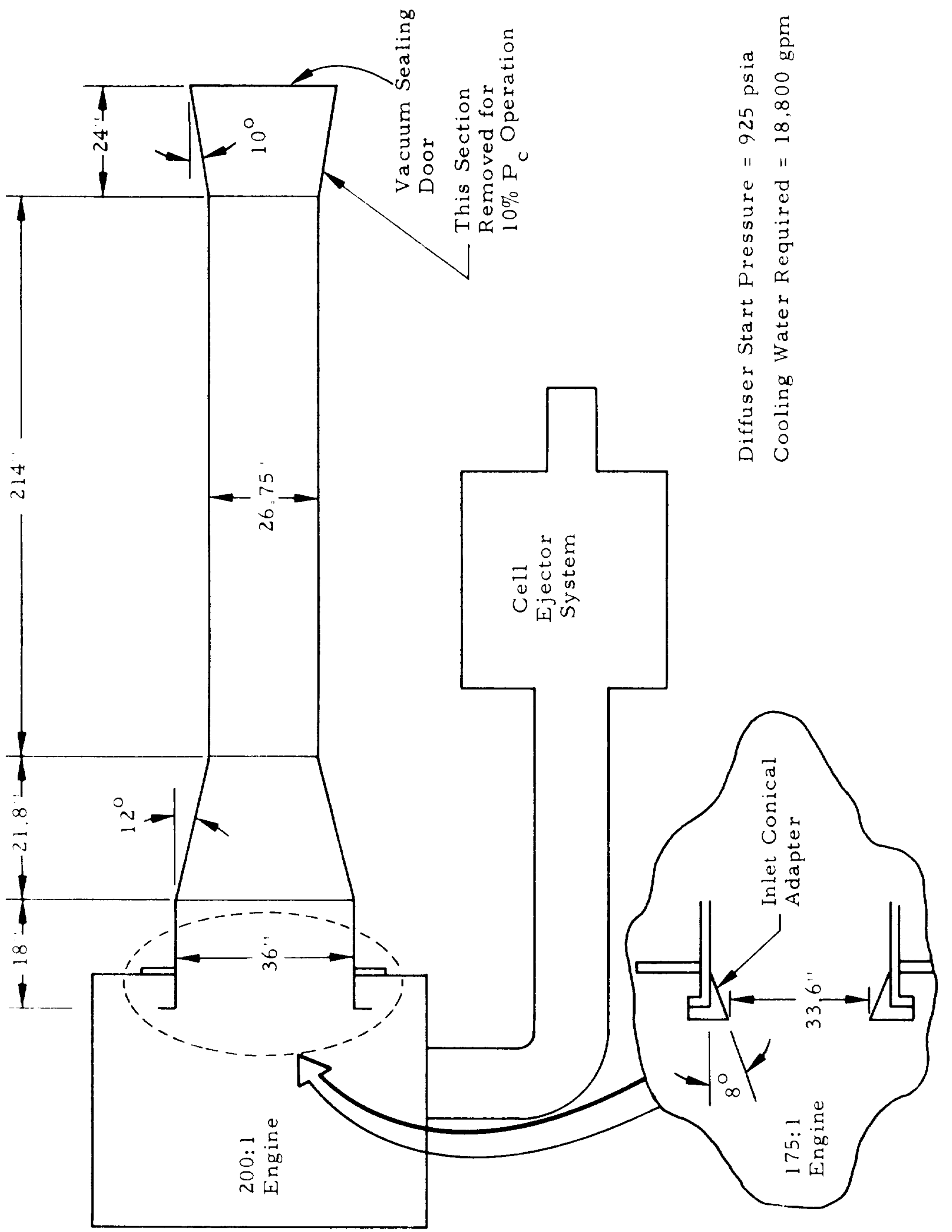


Fig. 1 - ASE 200:1 and 175:1; 100% P_c Operation

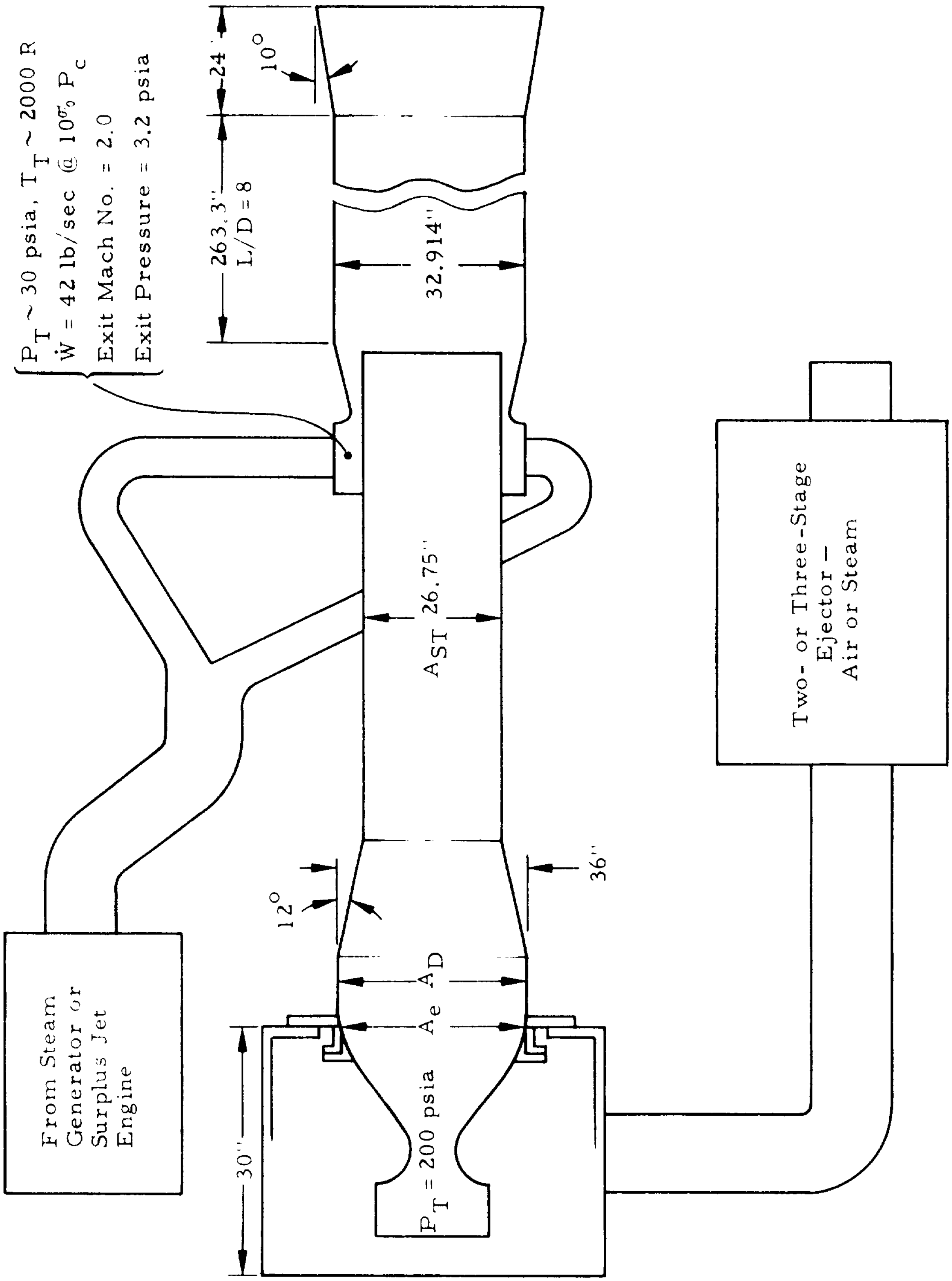


Fig. 2 - ASE 200:1 and 175:1, 10% P_c Setup